

# R&D and Technology Transfer: Firm-Level Evidence from Chinese Industry<sup>1</sup>

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## Abstract

In bridging the technology gap with the OECD nations, developing economies have access to three avenues of technological advance: domestic R&D, technology transfer, and foreign direct investment. This paper examines the contributions of each of these avenues, as well as their interactions, to productivity within Chinese industry. Based on a large data set for China's large and medium-size enterprises, the estimation results show that in-house R&D significantly complements technology transfer – whether of domestic or foreign origin. Foreign direct investment, which we assume is an important channel of proprietary technology transfer, does not facilitate the transfer of market-mediated foreign technology.

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## 1. Introduction

Along with institutional reform and political stability, technological progress is a critical ingredient for sustained economic growth and catch-up. Within the economies exhibiting substantial catch-up, including those of East and Southeast Asia, many technologically lagging firms learned to innovate by first imitating technologies created in developed economies. Imitation may occur through different channels, including market-mediated purchases of technology, technology transfer from multinational corporations to local subsidiaries or joint ventures, or the reverse engineering of products and capital goods. The relative contribution of these channels to technological advance has varied from country to country. While the Philippines and Thailand have been relatively open to foreign direct investment (FDI), Korea has tended to limit FDI but has relied on foreign technology transfer and indigenous R&D.<sup>2</sup> Overtime, with the establishment of formal R&D operations, many firms are making the transition from imitation to innovation, including the creation of patentable knowledge.<sup>3</sup>

For countries in which few firms have well-established R&D operations, tapping into the existing world knowledge stock would seem to be a natural way of bridging the technology gap, and arguably more efficient than trying to advance the domestic technology frontier through indigenous R&D effort alone. However, market failures that compromise the ability to appropriate returns to technology transfer, say through licensing, reduce the volume and sophistication of technologies that can be transferred through markets (Caves, 1992). Foreign direct investment provides a partial solution. With more

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<sup>2</sup> See, for example, Yusuf and Evenett (2002), Jefferson and Zhong (2004), Tables 12 and 13, and Westphal (1990).

control through direct equity participation, the parent company is likely to be more willing to part with more advanced technologies. One well-established motivation for FDI is to capture rents of proprietary assets that are difficult to appropriate through market transactions.

If R&D and technology transfer have independent and similar effects on a firm's knowledge base and productivity, we should expect to find the two types of innovative activity relating as substitutes. That is, technology transfer would substitute for the firm's internal R&D effort. This belief in the crowding-out effect of foreign technology on indigenous R&D effort motivated earlier efforts by the Indian government to restrict the purchase of foreign technology (Deolalikar and Evenson, 1989). However, technology transfer and R&D can also share a complementary relationship. Cohen and Levinthal (1989) argue that R&D not only involves innovation but also learning. A by-product of R&D is therefore to enhance a firm's absorptive capacity, which in turn boosts the efficacy of technology transfer. Drawing on the recent experience of East Asian economies, Kim and Nelson (2000) suggested that imitation through the adoption of existing technologies serves as an effective learning experience that paves the way for indigenous technological innovation.<sup>4</sup> In a recent study using industry data from OECD economies, Griffith, Redding, and Van Reenan (forthcoming) find evidence that supports the complementary relationship between R&D and technology transfer.

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<sup>3</sup> Many researchers have documented the experience of Korea and Taiwan in making the leap from imitator to innovator. See for example, Kim (1997) and Kim and Nelson (2000).

<sup>4</sup> A number of empirical studies have been concerned with Indian firms. These studies (Deolalikar and Evenson, 1989; Basant and Fikkert, 1996; and Katak, 1997) generally find significant returns to technology transfer and R&D, which relate as complements, rather than substitutes, as avenues of technology acquisition.<sup>4</sup> An exception is Ferrantino (1992), who does not find robust returns to R&D or technology transfer in Indian firms. Outside India, Braga and Willmore (1991) find robust complementarity between technology imports and firm technology effort in Brazilian industry.

Over the past two decades, China has become an important venue for technology transfer, foreign direct investment, and indigenous R&D.<sup>5</sup> Using an extremely rich firm-level data set of Chinese manufacturing firms, this paper investigates two questions regarding R&D, foreign and domestic technology transfer, and FDI. These are: Do in-house R&D and technology transfer contribute to productivity, and if so do they relate as complements or substitutes? Does FDI facilitate the purchase and adoption of foreign technologies?

By including data on domestic technology transactions, our data set also allows us to examine the role of domestic technology transfer. Many issues that have been raised in the literature concerning international technology transfer also relate to domestic technology transfer, particularly in a country as large and technologically heterogeneous as China.

The remainder of the paper consists of four sections. Section 2 describes the data used in this paper and discusses issues related to the construction of the sample and variables. In Section 3, we estimate the returns to R&D and the interactions between R&D and technology transfer and between FDI and technology transfer. Section 4 concludes with further observations and policy implications.

## **2. Data**

The data for this research, which span the population of Chinese large and medium size enterprises, are drawn from the Survey of Large and Medium Size Enterprises that China's National Bureau of Statistical (NBS) conducts each year.<sup>6</sup> Large and medium size

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<sup>5</sup> China's 2000 S&T census (NBS, 2001) reports that in that year, China's R&D spending as a share of GDP reached one percent, about one half that of the OECD average and a substantial increase relative to the level of 0.6 percent reported in 1995.

<sup>6</sup> Jefferson, Hu, Guan, and Yu (2001) provide a comprehensive description of this rich data set.

enterprises dominate Chinese industry,<sup>7</sup> in 2002 accounting for 59 percent of China's total industrial output (CSYB, 2003, p. 459). Our sample spans a period of five years from 1995 to 1999 and includes data for 29 two-digit manufacturing industries and over 400 four-digit industries.

Continuity of the data at the firm level, as provided by the panel, is important to our research strategy for two reasons. First, innovation and learning are path-dependent processes. A firm's past experience in innovating and imitating directly affects its future performance. Second, such continuity of the data at the firm level provides us with a tool to deal with the unobservable or un-measurable firm-specific characteristics in our econometric analysis. However, in our sample the data for all firms are not continuous. Due to ownership restructuring, which sometimes entails a change in identifiers, and the entry and exit of firms, many of the firms in the data set cannot be tracked over the full five-year period. By including all firms that report data for at least four of the five years, we create a semi-balanced sample of approximately 10,000 firms a year over the five-year period.<sup>8</sup>

Foreign (domestic) technology transfer is measured by a firm's expenditure on disembodied technology purchased from a foreign (domestic) provider, such as patent licensing fee and payment for blueprints of technology. When we calculate the intensity of

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<sup>7</sup> To define large and medium-size enterprises, China's NBS uses either of two industry specific criteria: production capacity or original value of fixed assets. For example, an iron and steel firm must meet or exceed a production capacity of 600,000 tons to qualify as a "large" enterprise. For semiconductor manufacturing firms, the original value of fixed assets of a "large" enterprise must exceed 50 million yuan. For further elaboration of the criteria used to classify firm size, see the web site of the China's NBS ([www.stats.gov.cn](http://www.stats.gov.cn)).

<sup>8</sup> We cannot precisely identify the nature of possible selection bias. Firms that are omitted from our sample are generally of two types – those that have reduced their size and have become classified as "small-size" and those that have experienced formal ownership conversion, particularly conversion that has involved an industry reclassification, change of address, or change in size classification (within the broader class of large and medium-size firms). **Statistics in Table 1 do not indicate any systematic difference between the omitted and the included samples.**

R&D, foreign technology transfer, and domestic technology transfer across China's 29 two-digit manufacturing industries, we find several patterns.<sup>9</sup>

First, foreign technology transfer tends to be relatively more intensive in the technologically less advanced industries, i.e. tobacco, textile, apparel, leather, furniture, paper, printing, and rubber, in which firms spend equal or greater amounts on foreign technology transfer than on R&D. The industries usually thought to be more technologically sophisticated, such as pharmaceutical, electric, electronics, and instruments, invest far more in R&D than in technology transfer. In sharp contrast to their foreign counterparts, domestic suppliers seem to be an insignificant source of technology transfer.

Following the methods of Griliches (1979), we construct stock measures for each of the three technology variables – R&D, foreign purchased technology, and domestic purchased technology – to examine their roles in shaping firm performance. Knowledge accumulated through these three activities in the past generates benefits in the present and the future thereby making technological innovation an inherent path-dependent process. However, knowledge becomes obsolete and therefore depreciates due to the passage of time and the emergence of new knowledge taking its place. Using a perpetual inventory model, we construct the stocks of R&D, foreign technology transfer, and domestic technology transfer as the discounted sum of past expenditures on the respective activity. The stock measures of the three technology variables are based on the assumption of a discount rate of 15 percent.<sup>10</sup>

***[Insert Table 1 here]***

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<sup>9</sup> Intensity is calculated as the average ratio of the relevant expenditure to sales revenue; we weight each firm's intensity by the firm's share of total industry sales.

<sup>10</sup> This seems to be the rate that most, if not all, R&D researchers use. As in many studies, our estimation results prove not to be sensitive to the choice of the discount rate.

Table 1 provides additional information about the sample, including the mean and standard deviation for key variables for each of the sample years and the whole sample. The statistics show several important changes that have been taking place in China's large and medium size enterprise sector. First, during the latter half of the 1990s, these Chinese firms were shedding employees and becoming more capital intensive. The average number of workers per firm decreased from 1,528 in 1995 to 1,292 four years later. During the same period, the average capital-labor ratio nearly doubled from 44 thousand yuan per worker to 84 thousand yuan. Second, labor productivity as measured by value-added per worker rose significantly, if not steadily, while total profits were relatively stable, implying that, whether measured by sales or assets, profitability fell during this period. These two seemingly contradictory observations – rising labor productivity and declining profitability – can be partially explained by increasing competition in China's industrial sector, which has squeezed profit margins across all Chinese enterprises. State-owned enterprises, which dominate our sample, have been particularly hard hit, losing monopoly power in an increasing number of industries and having to meet competition from all corners of the economy, particularly from the private sector and foreign invested enterprises.

### **3. R&D, technology transfer, and productivity**

We examine the potentially different impacts of R&D and technology transfer on a firm's economic and technological performance by estimating a production function in which R&D expenditure and the two measures of technology transfer serve as inputs to a productivity function that we embed in the production function. By examining the channels – direct and interactive – through which R&D and technology transfer affect

productivity, we compare and contrast the avenues through which these different sources of innovation operate.

### 3.1 The production function and estimation issues.

We first specify and estimate a value-added Cobb-Douglas production function:

$$Y_{it} = A_{it} C_{it}^{\alpha} L_{it}^{\beta}, \quad (1)$$

where  $\alpha$  and  $\beta$  are the output elasticities of capital and labor.  $A$  is the total factor productivity parameter, which is driven by R&D, technology transfer, and industry and ownership characteristics. We characterize the evolution of productivity by:

$$A_{it} = e^{f(K_{it}^F, K_{it}^D, K_{it}^R) + rt + \sum_j \gamma_j I_j + \sum_h \delta_h W_h + \sum_s \lambda_s T_s} \quad (2)$$

where  $r$  is the economy-wide rate of autonomous technical progress. Inputs to the firm's knowledge production consists of three stocks: foreign technology transfer ( $K^F$ ), domestic technology transfer ( $K^D$ ), and R&D ( $K^R$ ). The industry dummies ( $I_j$ ) represent differences in technological opportunity across industries; the ownership dummies ( $W_h$ ) account for differences in incentive structures and policy regimes that vary systematically across ownership classifications; and the  $T_s$  are time dummies that capture year-to-year variations in productivity and prices. Absent clear theoretical guidance for the specific functional form of  $f()$ , we assume a relatively flexible specification that includes the log of the three stock measures and three pair-wise interactive terms. Substituting (2) into (1) and taking logarithms, we obtain the following value-added production function:

$$y_{it} = \alpha_0 + \alpha_1 c_{it} + \alpha_2 l_{it} + \sum_M \beta_M k_{it}^M + \sum_{M,N} \beta_{MN} k_{it}^M k_{it}^N + \sum_j \gamma_j I_j + \sum_h \delta_h W_h + \sum_s \lambda_s T_s + \varepsilon_{it} \quad (3)$$

where  $a = b + c$ , lower case letters denote logs,  $M, N =$  foreign ( $F$ ), domestic ( $D$ ), and in-house R&D ( $R$ ) and  $M \neq N$ . Industries and ownership groups are indexed by  $j$  and  $h$  respectively. Equation (3) allows us to estimate the returns to R&D and technology purchase and to ascertain the relationship between R&D and technology purchase through the interaction terms.

In estimating equation (3), we face a possible econometric problem concerning the potential correlation between the independent variables and unobservable or unmeasurable firm specific characteristics, such as heterogeneous managerial capabilities. It is quite likely that these firm specific characteristics are correlated with the production inputs on the right hand side of equation (3). For example, firms with exceptional managers that cause  $\varepsilon_{it} > 0$  may also sustain greater than average expenditures on technology transfer and R&D. The ordinary least square (OLS) estimates of the coefficients on the technology transfer and R&D variables would then be subject to omitted-variable misspecification and bias.

Various possibilities exist to correct for the bias. With panel data, an easy solution would be to “de-mean” the variables with a within or first-difference type of estimator. This procedure would rid equation (3) of the time invariant firm specific characteristics and allow for unbiased estimates of the output elasticities if all the unobservable or unmeasurable firm specific characteristics do not change over time. But this easy-to-implement procedure comes with a cost. For most panel data, particularly short panels such as this, most of the variation of the data is in the cross-section dimension. Applying a within estimator to the data not only eliminates the invisible firm specific characteristics but also wipes out useful inter-firm variation, which may account for most of the total

variation. Another problem is that, by reducing the amount of useful information in the variable, the within estimator is likely to exacerbate the bias introduced by measurement errors. This effect will bias the estimated coefficients toward zero. A stylized finding in the R&D literature (Griliches, 1984) is that studies using the production function framework usually find significant returns to R&D in the cross-section dimension. In the time-series dimension, the causal relationship between R&D and productivity is less robust. Our data and estimation results share this feature.

Another method – that which we use – is the instrumental variable (IV) approach. The ideal instruments should be correlated with the firm’s input choices but be independent of firm specific effects. Such instruments are hard to find. But Jaffe (1986) showed that proper industry variables could potentially become effective instruments to correct for firm specific effects. These variables define the environment in which the firms operate and yet are independent of a firm’s specific characteristics. In the IV estimation, we use the four-digit industry average of all the variables in equation (3) and the ownership, year, and industry dummies as instruments for all the input variables. Because the industry variables may not be entirely independent of firm characteristics that exhibit a distinct industry-specific bias, such as technological opportunity or managerial capability, which may differ systematically, say between the pharmaceutical and textile industries, we rely on the 4-digit industry dummies to capture these industry specific effects.

***[Insert Table 2 here]***

### 3.2 Results and discussion

We report eight sets of results in Table 2: two sets of OLS estimates, two sets of IV estimates, and four additional sets of IV estimates – one each for the scientific industries,

non-scientific industries, domestic firms and foreign invested firms. The full sample estimates include two variants – one with and one without the interactive terms involving the three technology variables. To save space, we do not report the estimated coefficients for the industry, ownership, and year dummy variables.<sup>11</sup>

### 3.2.1 The overall picture.

In Table 2, a common result across the regressions that omit the interactive terms, i.e., columns (1) and (3), is that the estimates on both R&D and foreign technology transfer are positive and quite significant,<sup>12</sup> whereas those on domestic technology transfer are negative and generally significant. By including interaction terms for the three technology inputs, column (4) provides strong evidence of complementary relationships between R&D and the two technology transfer variables. With the interactive terms, the coefficient of R&D remains significant and largely unchanged in magnitude, whereas the coefficient for direct foreign technology transfer declines from a highly significant positive value to an insignificant level. The coefficient on direct domestic technology transfer, a negative estimate, becomes more robust. In the same regression, the interaction between R&D and foreign technology transfer exhibits a positive and statistically significant impact on productivity. The estimate of the interaction between R&D and domestic technology transfer is also robust. While affirming the direct contribution of R&D to productivity, these results also indicate that technology transfer becomes significantly more productive

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<sup>12</sup> Note that the finding of significant and positive rates of return on R&D within Chinese industry are consistent with Hu and Jefferson (2004) and Jefferson et al (2004).

when the firm is also engaged in internal R&D. This result applies to technology purchased from both foreign and domestic suppliers.<sup>13</sup>

As well as corroborating the hypothesis that R&D enhances the firm's absorptive capacity and therefore makes the adoption of new technology more effective, the finding of complementarities also has important policy implications. In using its R&D policy instruments – direct grants (*shangji bokuan*) and tax incentives (*jianmian shui*) – to promote technology transfer, China's government should direct these policy instruments toward those industries and firms that both support active in-house R&D operations and utilize market-mediated technologies, whether domestic or foreign.

We use the results in Table 2, column 4 to compute the total (i.e. sum of the direct and interactive) effect of  $K^R$ ,  $K^F$ , and  $K^D$  on output (i.e., the marginal product of each) with sample means of the variables. The total effects are all statistically significant<sup>14</sup> and highlight a key finding of our analysis, which is that in-house R&D and market-mediated technology are complements.

### 3.2.2. Scientific vs. non-scientific and ownership differences

Due to the considerable heterogeneity of technological sophistication of the firms in our sample, we divide the full sample into two groups – scientific and non-scientific – and estimate equation (3) separately. We adopt the classification of previous authors (e.g., Griliches, 1984) with slight modification in view of the patterns of R&D intensity in

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<sup>13</sup> Using the sample average (“all”) R&D stock figure in Table 1, we compute the total elasticity of value added (i.e. productivity) with respect to domestic technology transfer to be 0.022, i.e., a positive estimate.

<sup>14</sup> We re-estimate column (4) of Table 2 replacing the technology variables with the deviation from the sample mean, i.e., we replace  $x$  with  $(x - \bar{x})$ ,  $\bar{x}$  being the sample mean of  $x$ . The coefficients on the  $x$ 's are all statistically significant. The marginal productivities of  $K^R$ ,  $K^F$ , and  $K^D$  are respectively 0.131, 0.067, and 0.009.

Chinese. The scientific group includes chemical, pharmaceutical, chemical fiber, ordinary machinery, special equipment, electric, electronics, and instruments.

Overall, the results we obtain with the full sample largely carry through for scientific firms. In column (5), the R&D-productivity link for the scientific group is even stronger than in the full-sample regressions. While the direct impact of stand-alone R&D is magnified in the scientific group, the complementarity between R&D and technology transfer, both foreign and domestic, remains literally unchanged. In the non-scientific group, the direct R&D-productivity link disappears, although R&D continues indirectly to complement foreign technology transfer. For the non-scientific group, the complementarity of domestic technology transfer with internal R&D disappears, even though the direct impact of domestic technology purchases remains negative. In the scientific group, we find three sources of productivity advance – direct R&D and the interactions of R&D with both purchased foreign and domestic technology. By comparison, in the non-scientific group we find only one effective innovation channel, which is the interaction between R&D and foreign technology.

In Table 2, each of the regressions includes ownership dummy variables to control for ownership specific effects. The eight ownership groups are state-owned enterprises (SOE), collective-owned enterprises (COE), private enterprises (PRE), limited liability companies (LTE), jointly operated enterprises (JOE), stock-incorporated enterprises (SKE), foreign invested enterprises (FIE), and Hong Kong-Taiwan-Macao invested enterprises (HMT). The productivity ranking (not reported) starts with FIEs at the top, is followed by HMTs and concludes with SOEs at the bottom. The pattern is consistent across all

regressions and is compatible with earlier studies (e.g., Jefferson, Rawski, Zheng, and Li , 2000).

### 3.2.3 Does foreign ownership lead to more efficient technology transfer and adoption?

Earlier, we introduced the hypothesis that foreign ownership might have an impact on the efficacy of foreign technology transfer. We should expect this if a foreign invested firm is more likely to transfer more advanced and appropriate technology from the firm's foreign parent, i.e. the multinational corporation, since the latter may be more willing to part with proprietary technology given its equity stake in the firm. In Table 2, we find support for this proposition, since the productivity levels for FIE and HMT firms lie significantly above the productivity of all forms of domestic ownership.<sup>15</sup>

But how does foreign equity participation affect the propensity to engage in successful arms-length market-mediated technology transfer? One possibility is that, with its expertise in the field, the foreign party in the firm may be able to help the firm identify appropriate international technologies to license that would be obtained from other international sources. Moreover, the legal connection of the foreign subsidiary to a foreign-based parent firm may ensure greater compliance with intellectual property rights law so as to reassure potential suppliers that restrictions on the use of transferred technology will be honored. An alternative conjecture is that the creation of the subsidiary foreign firm as a conduit for technology within the expanded boundaries of the firm serves as a substitute for market-mediated technology transfers. The creation of a direct link between a parent company and its Chinese subsidiary reduces the need for the purchase of foreign

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<sup>15</sup> In a survey of Chinese firms engaged in foreign technology transfer, Wang (1999) cites this foreign ownership effect as an important determinant of successful technology transfer. The high productivity levels for FIE and HMT forms shown in Table 2 may also result from the transfer of embodied technologies, such as imported equipment.

technology. To test these contending conjectures, we repeat the production function estimates for four ownership groups and report the results in the last two columns of Table 2.

*[Insert Table 3 here]*

Table 2, Column (7) combines the domestic ownership classifications into one group.<sup>16</sup> We compare these estimates with those shown in Column (8) for the foreign-invested firms (FIEs), whose foreign investment largely originates with OECD-based parent firms.<sup>17</sup> While for both the domestic sample and the FIEs all of the general results carry through, only those for the domestic firms are statistically significant at the five percent level or better. The interactive results remain robust, but the results for the domestic firms and foreign firms show distinct differences. On the domestic side, the interactive terms for R&D and both sources of technology transfer – domestic and foreign – remain statistically significant at the one percent level. For the foreign firms, however, the interaction of R&D and domestic technology transfer become insignificant. The interaction of R&D and foreign technology transfer remains robust, but the statistical significance of these estimates for the FIE sample is considerably less than it is for the domestic group. Our results show that foreign equity participation weakens the tendency of Chinese firms to absorb market-mediated technology. On balance, we find support for the proposition that foreign direct investment tends to substitute for market-mediated technology transfer. Rather than interfacing more efficiently with technology markets,

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<sup>16</sup> Combining the sub-samples of SOE and non-SOE firms does not cause any change in either the sign or statistical significance of the relevant estimates.

<sup>17</sup> Various studies (e.g., Pomfret, 1991, and Hu and Jefferson, 2002) have commented on differences in the relative technological sophistication of OECD-based FIEs in comparison with overseas HKT firms. We do find significant differences as predicted and therefore focus our analysis of the sample of FIEs.

FDI firms appear to be achieving their foreign technological advantage through informal channels that become available to MNCs by expanding the boundaries of the firm abroad.

#### **4. Conclusions and policy implications**

A central finding of our research is evidence of strong returns to both R&D and technology transfer in Chinese firms. Against this background, we have identified two additional findings. The first finding is that the impacts of both domestic and foreign technology transfer on firm productivity are largely conditional on their interactions with in-house R&D. This finding reinforces empirical work for other developing economies that underscores the critical role on in-house R&D capabilities as an important channel for absorbing externally acquired technologies.

Our second finding is that proprietary technologies that are transferred through foreign equity participation are largely independent of market-mediated technology transfer. Domestic technology transfer, which interacts with in-house R&D in domestic firms, is not important for the foreign sector. The complementary relationship between foreign technology transfer and in-house R&D that we find for the domestic firm sector does operate in the foreign sector. While FDI may create a channel that reduces the transaction costs of technology transfer within the firm, the presence of foreign investment and foreign expertise does not enhance arms-length market-mediated foreign technology transfer.

Developing country governments sometimes find themselves in the position of promoting indigenous R&D for fear that purchasing off-the-shelf technologies from developed economies may crowd out domestically-sponsored R&D. Our analysis shows that R&D and technology transfer are not substitutes. Both R&D and foreign technology

transfer exhibit positive returns but their roles in boosting firm performance are quite different. When combined with R&D, foreign technology transfer generates measurable productivity gains; the addition of technology transfer – both foreign and domestic – raises the returns to indigenous R&D. Interactions among indigenous R&D and market-mediated technology transfer are clearly playing a role in facilitating China’s technological advance.

Our results are subject to a two caveats which warrant further research, one relating to research methodology, the other relating to the absence of smaller firms in our sample. As emphasized in Section 3 of the paper, with value added as the dependent variable and productivity shocks embedded in the error structure, ample opportunity exists for endogenous effects on the three stock measures of technology input that serve as explanatory variables. We have attempted to address these potential endogeneity problems by using four-digit industry averages as instruments for these dependent variables as well as four-digit industry dummies to capture omitted firm-specific variables. While we believe that these instruments have effectively controlled for endogeneity, we cannot be fully confident that the instruments using industry level data are entirely independent of the noise embodied in the error structure of the estimation equations. For this reason, the causality running from the set of technology inputs to firm performance and the mutually supporting complementarities between R&D and technology transfer may in some measure be correlations that arise from firm effects that have not been fully expurgated rather than the economic structure implied by our model. A longer time series will help to confirm the direction of these economic relationships. Furthermore, this paper examines only large and medium size enterprises. It will be of great interest to investigate similar issues in small enterprises, which form the vast majority of firms in China’s dynamic private sector.

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| <b>Table 1. Sample statistics</b>  |          |          |          |          |          |          |
|------------------------------------|----------|----------|----------|----------|----------|----------|
|                                    | 1995     | 1996     | 1997     | 1998     | 1999     | All      |
| Number of firms                    | 9,556    | 11,615   | 11,650   | 11,282   | 9,940    | 54,043   |
|                                    | (7,519)  | (6,971)  | (7,094)  | (6,525)  | (7,504)  | (35,613) |
| Employment                         | 1,528    | 1,457    | 1,427    | 1,351    | 1,292    | 1,411    |
|                                    | (1,371)  | (1,192)  | (1,159)  | (1,124)  | (1,036)  | (1,178)  |
| Capital labor ratio                | 44       | 58       | 65       | 74       | 84       | 65       |
|                                    | (42)     | (59)     | (74)     | (104)    | (123)    | (80)     |
| Labor productivity                 | 28       | 34       | 35       | 35       | 40       | 35       |
|                                    | (23)     | (27)     | (33)     | (43)     | (56)     | (37)     |
| Profits                            | 21,706   | 18,788   | 19,298   | 17,950   | 20,184   | 19,496   |
|                                    | (19,735) | (13,963) | (15,225) | (17,059) | (19,669) | (17,202) |
| R&D stock                          | 2933     | 2712     | 2863     | 3129     | 3400     | 2997     |
| Foreign technology transfer stock  | 1,961    | 1,760    | 1,948    | 2,251    | 2,447    | 2,065    |
| Domestic technology transfer stock | 258      | 267      | 278      | 278      | 286      | 274      |

Note: The unit of monetary variables is thousand yuan. The exchange rate between yuan and U.S. dollar during the sample period fluctuates in a narrow range between 8.27 to 8.35 yuan per dollar (NSB, 2001). The figures in parentheses are means for the observations excluded from the analysis.

**Table 2. The production function**

|  | OLS                |                      | IV                  |                    | Scientific         | Non-<br>scientific  | Domestic           | FIE                 |
|--|--------------------|----------------------|---------------------|--------------------|--------------------|---------------------|--------------------|---------------------|
|  | (1)                | (2)                  | (3)                 | (4)                | (5)                | (6)                 | (7)                | (8)                 |
| Log C                                  | 0.461*<br>(0.006)  | 0.457*<br>(0.006)    | 0.524*<br>(0.023)   | 0.507*<br>0.023    | 0.464*<br>(0.047)  | 0.530*<br>(0.025)   | 0.514*<br>(0.027)  | 0.701*<br>(0.126)   |
| Log L                                  | 0.539*<br>(0.007)  | 0.536*<br>(0.007)    | 0.418<br>(0.025)    | 0.417*<br>(0.025)  | 0.365*<br>(0.049)  | 0.455*<br>(0.028)   | 0.347*<br>(0.028)  | 0.099<br>(0.164)    |
| Log K <sup>R</sup>                     | 0.007*<br>(0.001)  | 0.005*<br>(0.001)    | 0.029*<br>(0.011)   | 0.027**<br>(0.01)  | 0.064*<br>(0.017)  | 0.003<br>(0.016)    | 0.028**<br>(0.013) | 0.092***<br>(0.041) |
| Log K <sup>F</sup>                     | 0.005*<br>(0.001)  | -0.003***<br>(0.001) | 0.032*<br>(0.005)   | -0.007<br>(0.004)  | -0.006<br>(0.007)  | -0.005<br>(0.006)   | -0.004<br>(0.005)  | -0.022<br>(0.018)   |
| Log K <sup>D</sup>                     | -0.007*<br>(0.002) | -0.012*<br>(0.002)   | -0.011**<br>(0.005) | -0.018*<br>(0.001) | -0.019*<br>(0.005) | -0.012**<br>(0.006) | -0.019*<br>(0.004) | -0.037<br>(0.025)   |
| Log K <sup>F</sup> *Log K <sup>R</sup> | -                  | 0.002*<br>(0.0003)   | -                   | 0.01*<br>(0.001)   | 0.009*<br>(0.002)  | 0.011*<br>(0.002)   | 0.012*<br>(0.001)  | 0.008***<br>(0.004) |
| Log K <sup>D</sup> *Log K <sup>R</sup> | -                  | 0.001*<br>(0.000)    | -                   | 0.005*<br>(0.001)  | 0.006*<br>(0.002)  | 0.002<br>(0.002)    | 0.007*<br>(0.002)  | -0.014<br>(0.013)   |
| Log K <sup>D</sup> *Log K <sup>F</sup> | -                  | 0.002*<br>(0.000)    | -                   | -0.001<br>(0.001)  | -0.001<br>(0.002)  | -0.001<br>(0.002)   | -0.002<br>(0.002)  | 0.005<br>(0.008)    |
| Ownership dummies                      | yes                | yes                  | yes                 | yes                | yes                | yes                 | no                 | no                  |
| Industry dummies                       | yes                | yes                  | yes                 | yes                | yes                | yes                 | yes                | yes                 |
| Time dummies                           | yes                | yes                  | yes                 | yes                | yes                | yes                 | yes                | 3263                |
| Number of obs.                         | 54043              | 54043                | 54043               | 54043              | 21768              | 32275               | 47719              | 3263                |
| Adjusted R <sup>2</sup>                | 0.54               | 0.54                 | 0.530               | 0.520              | 0.450              | 0.560               | 0.481              | 0.490               |

\*Statistically significant at the 1% level; \*\*statistically significant at the 5% level; \*\*\*statistically significant at the 10%.